Renewable and Sustainable Energy Reviews 30 (2014) 401–411

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Making the deployment of pico-PV more sustainable along the value chain

Stephanie Hirmer*, Heather Cruickshank

Centre for Sustainable Development, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK

A R T I C L E I N F O

Article history:
Received 13 April 2013
Received in revised form
14 September 2013
Accepted 19 October 2013
Available online 13 November 2013

Keywords:
Product diffusion
Solar lantern
Product acceptance
Sustainable product distribution
After-sales service
Pico PV

A B S T R A C T

Pico-PV is an excellent technology for bringing electric light to rural areas in the developing world and replacing kerosene lanterns and candles. However, as pico-PV is a comparatively new technology, relatively little is known about appropriate methods for sustainable product development and deployment. For this reason current dissemination methods are often ineffective and unsustainable. This research aims to help project developers deploy pico-PV technologies successfully and in a sustainable manner. To achieve this, a conceptual framework of key sustainability criteria along the value chain was developed and tested. The analysis revealed that the most important criteria for the sustainable deployment of pico-PV systems are: (a) easy and safe operation of the product; (b) that a system for product return is established; (c) the retailer understands the target market and (d) the end-user is aware of the product's existence and its benefits. This research reveals that criteria (b) and (c) are of greatest concern. In light of these findings, the authors propose to focus on the following five factors; namely: (a) raising awareness for certification and creating market reassurance; (b) introducing support mechanisms to facilitate local repair; (c) using existing supply channels and establishing in-country (dis) assembly; (d) introducing financial support mechanisms at product supply stages and; (e) undertaking marketing campaigns.

© 2013 Elsevier Ltd. All rights reserved.

Contents

* Corresponding author. Tel.: +44 1223748216.
E-mail addresses: sah93@cam.ac.uk, stephi.hirmer@gmail.com (S. Hirmer), hjc34@cam.ac.uk (H. Cruickshank).

1364-0321/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2013.10.018

1. Introduction

This review seeks to explore methods to deploy small-scale solar technologies (pico-PV) more sustainably in the developing world. This is important as the technology is becoming increasingly common as a substitute for traditional lighting methods such as kerosene lanterns and candles. It is predicted that by 2015 the market penetration of small-scale solar products will increase to 8% from the baseline figure of 0.5% in 2010 [1]. For example, it is believed that 40 million households alone in rural areas of Ethiopia, Ghana, Kenya, Tanzania, and Zambia could benefit from small-scale solar solutions [2]. Sparsely populated areas and low energy consumption, however, remain key barriers to rural electrification in the developing world [3,4]. These are synonymous across rural electrification technologies [3]. As Lahimer et al. states "*rural electrification is a complicated issue because of user affordability, rural inaccessibility and remoteness, low population densities and dispersed households, low project profitability, fiscal deficit, scarcity of energy resources, population growth, lack of professionalism, and over-dependence on subsidies*" [5]. Subsequently, at present, developers face deployment and implementation barriers when making products accessible to rural customers [6,7]. One reason for this may be the lack of attention given to market-based factors such as access to markets, local roads and transportation, communications, access to finance, local skills and competition [8]. This is in line with the findings from Polak [9]. He studied a variety of appropriate technologies and found that the lack of resources for scaling up, the ineffective branding and marketing, the high costs and the weak distribution channels inhibit the sustainable diffusion of products [9]. Further to this, Hammond et al. found the adopted market-based approaches used to design and distribute products in the developing world are a constraining factor [10]. According to McKinsey, a management consultancy, speed and scale are key components when deploying technologies in emerging markets [11]. Whilst concepts such as 'appropriate technology', 'product diffusion' and 'rural electrification' touch upon the sustainable project and product deployment, the authors found no evidence of research that comprehensively addresses a wide variety of aspects specific to pico-PV products – the focus of this research. To date, a rich collection of literature focuses on the technology [4,12,13] and economic aspects [14–17] of PV. This in turn is translated into new innovative business models for pico-PV [10,18–25]. This is in line with the findings from Chaurey et al. who found that there is a large volume of literature with insights into technological, economic, commercial, and social aspects of PV but a lack of literature that comprehensively addresses all aspects of development of PV projects [6]. According to Frischmann, the overemphasis on design of projects in the developing world leads to a lack of attention on the actual service and end-user interaction [26]. However, according to Palit technical, financial, institutional, and governance barriers remain a challenge in a rural electrification context [27]. Subsequently, these issues are also addressed in this research.

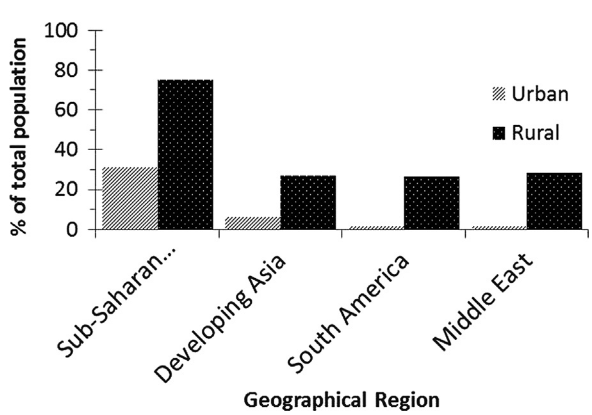

Fig. 1. Rural and Urban population without access to electricity [31].

This research seeks to fill the above identified gap by answering the question: "What are the prevailing aspects for the sustainable deployment of pico-PV products, considering the needs of the different stakeholders along the value chain and how can these be overcome?" To address this, the authors developed and tested a conceptual framework. Using a wide variety of literature (e.g. from the fields of energy efficient biomass stoves, to appropriate technologies and product diffusion) 40 sustainability criteria applicable to the sustainable deployment of pico-PV were identified. These characteristics were then verified through expert opinions (focus group meetings). Following this, 35 expert interviews (with first-hand experience in the deployment of pico-PV) were conducted. Expert disciplines included: (a) product designers and manufacturers, (b) importers, distributors and project developers, and (c) development workers and energy advisors. Based on these findings, recommendations to stakeholders along the pico-PV value-chain are given. This research does not examine the consequences of replacing traditional lighting methods with pico-PV technologies on society. Instead, in line with the views of Müggenburg et al. pico-PV is seen an appropriate technology. By definition an appropriate technology is "… designed to take account of the social, economic, and environmental circumstances in which it is employed, often aiming to meet a specific practical need…" [28]. Therefore, any improvements made to the development and deployment of pico-PV products will have a positive effect on society.

This paper is separated into three sections. Firstly, the status quo of rural electrification in the developing world is outlined. Secondly, a conceptual framework for pico-PV is developed taking into consideration the needs of the different stakeholders. Thirdly, key sustainability criteria are discussed. Finally, the paper concludes by identifying areas of greatest needs, giving key recommendations for the sustainable deployment of pico-PV products.

1.1. Status quo rural electrification in the developing world

Despite global mobilisation approximately 1.3 billion people (25% of the world population) lack access to electricity [29]. Sub-Saharan Africa (SSA) has the lowest electricity access rate in the world [30] with the majority of people living in rural areas (Fig. 1).

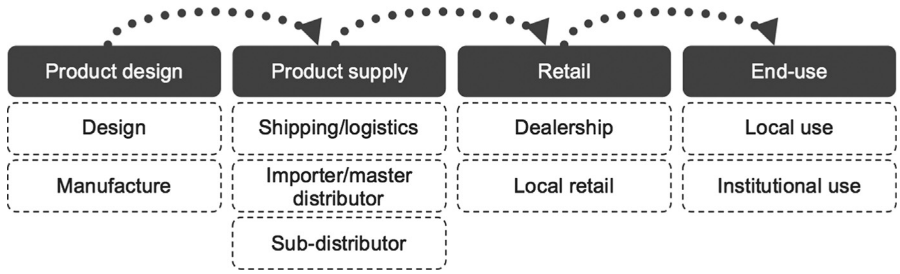

Fig. 2. Value chain stages and sub-stages of pico-PV development and deployment [44].

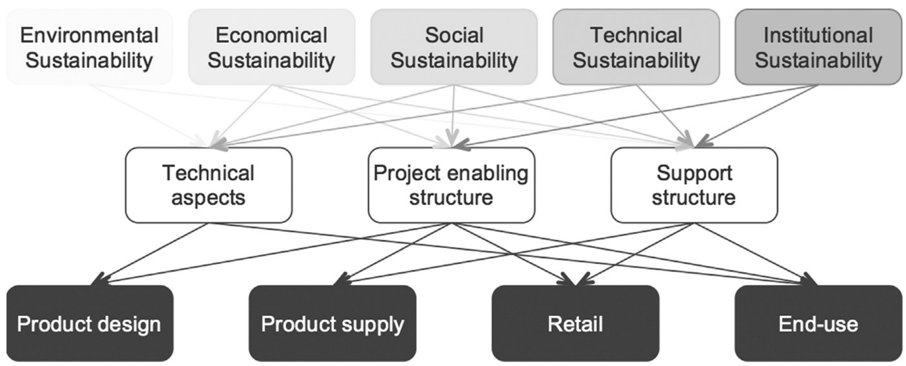

Fig. 3. Linkage of sustainability dimensions to project categories and the pico-PV value chain.

While the lack of energy access is predicted to decrease in Asia and Latin America, the number of people without access to electricity in SSA is predicted to increase by 10% (from 586 million to 645 million) by 2030 [18]. This is because population growth currently outpaces grid connections [32,33]. As rural electrification rates remain low [34], people continue to use traditional lighting methods despite their health, safety, environmental and financial risks [6,35].

Notwithstanding the low power output of pico-PV systems,[1] they are seen as a promising technology for bringing light to rural areas in the developing world and replace kerosene lanterns [25,36]. Kerosene lamps are the most common off-grid lighting technology with almost 2 billion users worldwide [37]. They account for 190 million tonnes of CO_2 emissions per annum [38]. It is estimated that close to US $40 billion is spent on kerosene lighting each year at the Bottom of the Pyramid (BoP)[2] [37]. By replacing traditional lighting methods, indoor air pollution and heat can be reduced [39,40]. Additionally, pico-PV products reduce the health risks, for example from accidental burns [1].

However, despite the variety of different pico-PV products available and the significant investments made to improve the design of pico-PV lanterns, uptake remains low [41]. Users often purchase cheap, low quality products resulting in high levels of electronic waste since products have short life spans and cannot be maintained [42]. This harms the reputation of solar technologies, destroys consumer confidence and is detrimental for the future of the pico-PV industry [28]. There is therefore a clear need for increased efforts in sustainable product deployment and diffusion as pico-PV products are relatively new to the market and few standards exist on sustainable product development and deployment.

1.2. Pico-PV value chain

Different market models are used to bring pico-PV products to the end user. These can be categorised into four distribution models: institutional partners; company owned branches; micro-franchises; and traditional distribution models[3] [43]. Despite these different deployment approaches and the involvement of multiple parties, it is possible to summarise the pico-PV value chain in four stages (shown in Fig. 2).

2. Development conceptual framework for pico-PV products

A review of development literature yields a number of different sustainability dimensions and concepts. 'The Brundtland Report' sets out the first and still most widely used definition of sustainable development [45] as meeting current needs without hindering potential future development by overuse of resources [46]. In particular it emphasised the important requirement to prioritise the needs of the world's poor. A concept which is embedded within this research. Definitions of sustainability and sustainable development have proliferated since the report was written with hundreds of actors developing their own criteria for sustainability [45,47]. However, these conceptual definitions are only partially reflecting real world applications in which practical and tangible considerations have priority. Additionally, the separation of the system into individual dimensions is a very artificial process and hides the real connections; as each dimension represents a complex, non-linear and self-organising system [48]. In line with Ramírez et al. a pico-PV system can be seen

[1] Pico-PV has the smallest power output of the solar technologies available on the market for lighting and is the cheapest entry point for using solar power [12]. In addition to lighting, pico-PV can provide radio and mobile phone charging services [43]. Systems are available in a variety of forms with a solar panel, battery and LED light [28].

[2] The 'Bottom of the Pyramid' (BoP) model developed by Prahalad and Hart [62] refers to people at the lowest socio-economic group. Currently approximately 4 billion people live in relative poverty with a purchasing power of less than US $3000 per year [10].

[3] Manufacturer sells to the distributor, who in turn sells to dealerships. These have sub-dealers or micro-entrepreneurs that sell the product to the end-user [43].

as "*a sustainable energy system* […which is] *clean, safe, reliable, just, affordable and accepted by the public, and guarantees flexibility, continuity and independence*" [49]. Henceforth there is a need to focus on product delivery, business continuity and the longevity of the project to ensure the sustainability of the entire system. Consequently, the sustainability dimensions and criteria that contribute to a sustainable development and deployment of a pico-PV system can be categorised into the following three project elements: (a) technical considerations, (b) project enabling structure and, (c) support structure. These project elements, in relation to the five sustainability dimensions: environmental, economic, social, institutional and technical [50,51], provide the main skeleton for identifying sustainability factors pertaining to the development and deployment of pico-PV along the value chain. Fig. 3 shows the complex links between the different dimensions.

There are a variety of different conceptual frameworks available in literature. However, no framework applicable to pico-PV was found in this literature review. Consequently, in order to develop a framework for pico-PV the literature review for this study drew on a wide variety of literature (appropriate technology, product diffusion, photovoltaic and biomass stoves). For example biomass stoves, much like pico-PV products, require the users to replace an existing appliance with a more energy efficient technology. In both cases, the new technology's benefits may not initially be clear to the end-user. Additionally, there are over thirty years' of experience in the sustainable implementation of energy efficient stoves in the developing world [52]. Different aspects pertaining to pico-PV at the three project elements (technical considerations, project enabling structure and, support structure) are discussed below.

2.1. Technical aspects pertaining to pico-PV products

At present, to meet the financial capacities of the target group and generate high profits, many of the available pico-PV products targeted at BoP customers are of bad quality and often equipped with highly toxic batteries [53]. Additionally, products are often designed with little consideration of customer context (*ibid*). Frequent early product failure is symptomatic of poor quality [12,54]. This adversely affects the market as customers become disillusioned which may discredit the entire technology in the eyes of consumers [28]. The early breakage is detrimental for the environment as products are simply thrown away since, for example, a system for safe disposal and recycling of batteries is not available in most cases [55]. From the literature (see Footnotes 5–8), four key criteria that can improve product design were identified.

- Minimise environmental harm through sensible material choice[4]
- Ensure product meets the financial capacity of the target group[5]
- Provide quality products that are easy and safe to operate[6]
- Ensure product meets the needs and wants of the target group[7]

2.2. Project enabling structure for pico-PV products

Similar to stoves, the uptake of pico-PV remains low [41]. This is because product supply and distribution is often difficult as many importers and retailers lack the financial capacities to purchase products in advance [56]. Further to this, there is a clear difficulty in reaching rural customers that have otherwise little chance to change their energy situation in the near future (*ibid*). Due to the missing sales infrastructure project developers are unable to facilitate regular product supply [37]. To overcome this, many products are being sold through existing retailers. However, retailers may lack the necessary skills to effectively sell and market the products; a necessity for market development [54,57,58]. It is essential that rural customers understand the benefits of the products and feel a real need for pico-PV. "*Product adoption was highest in villages where fuel prices* […] *were high and villagers had an explicit need to save fuels*…" [56]. This indicates that end users must be motivated to adopt the new technology. The following aspects can ensure a better project enabling structure:

- Ensure supplier, retailer and end-user has reliable access to finances[8];
- Ensure the retailer has, in addition to the core business skills, the ability to effectively sell and market the product[9];
- Ensure end-user has continuous access to products through an effective supply and distribution network.[10]

2.3. Support structure for pico-PV products

Currently, despite the short lifespan of pico-PV and the product misuse that leads to early product breakage, a functional replacement and repair service for people living in remote areas does not exist [59]. This may be because (a) there is a lack of sufficient infrastructure that can facilitate product return or repair; and (b) setup is a capital-intensive process [8,9]. Additionally, to reduce unwanted product disassembly, many pico-PV systems are designed as an entire unit [54], the major drawback being difficulty in repair and replacement of parts and product disposal. Customers at the 'Bottom of the Pyramid' do not have the financial capacities to repair the product without guaranteed after-sales support. Both the lack of a repair/replacement infrastructure and the difficulty to exchange broken components leads to products being simply thrown away, littering the area and harming the environment [54,59]. There are a number of aspects that can be put in place to facilitate an effective support structure; these are as follows:

- Include cost of the support infrastructure into the product price as this cannot be carried by the customer or by the environment[11];
- Provide appropriate guidance for correct product handling and repair, such as graphical manuals and training guides[12];
- Ensure customers have access to repair or replacement services; product replacement needs to be ensured at each stage along the value chain.[13]

From the above discussion a number of key sustainability criteria were identified. These sustainability criteria were tested and refined in a number of focus group meetings with energy experts. Subsequently, 40 sustainability aspects applicable to pico-PV were identified (shown in Table 1).

3. Findings and discussion

The following discussion will draw on the findings from the 35 expert interviews. Experts had first-hand experience in the

[4] [63–66].
[5] [56–58,63–65,67–71].
[6] [52,56–58,63–66,68,69,71,72].
[7] [52,57,58,63,65,66,68–70,73,74].
[8] [52,58,64,65,69,70,74].
[9] [52,57,58,64–66,69,73,74].
[10] [52,56–58,64,65,67,68,70,74,75].
[11] [52,56,64,69].
[12] [52,56–58,64,65,69,70].
[13] [52,64,65,69,70,74].

Table 1
40 sustainability criteria pertaining to pico-PV along the value-chain.

Value chain	Sustainability criteria
Product design stage: for end-user	Undertake baseline study Conduct market research Undertake technical performance study (> 1 year) Consult experts that understand the target group Product is easy and safe to operate Final price adequate for target group Informative packaging
Product design stage: for end of product use	Environmentally friendly product (to highest possible extent) Functional warranty exists Product certified externally Manufactured with quality materials and components Graphical repair and training guide exists Spare parts is available Repair kit is available
Product supply stage: supply chain	Reliance on established supply channels Supply chain appropriate for local conditions Product is available on the market A product return and repair system exists Importer has sufficient liquidity A system for (partial) assembly/disassembly or production exists in country Target area is supplied regularly
Retailer stage: physical retail capacities	Outlets are common across the target area/country or means of transport exists Retailer is capable of purchasing products in advance Retailer is capable of managing demand and supply of products Retailer is capable of facilitating product return Retailer has a large enough market to sustain business Retailer can offer a variety of products
Retailer stage: soft skills	Retailer has a good reputation Retailer has the capacity to undertake marketing Retailer has business skills to sell product Retailer is capable of undertaking basic repair tasks or Retailer understands the target market Retailer can communicate product benefits well Retailer has the skill to run an enterprise
End-user stage:	End-user has a need for alternative lighting methods End-user knows how to access repair services End-user is able to access finance to purchase products End-user is aware of product existence and benefits End-user knows where to find and has easy and non-expensive access to sales agents

deployment of pico-PV. They came from a wide range of backgrounds and covered a broad range of sectors, including: development agencies, NGOs and the private sector. Their disciplines included: (a) product designers and manufacturers; (b) importers; distributors and project developers; and (c) development workers and energy advisors. Interviews were held during June and July 2012. The majority were performed via Skype, but where possible were carried out in person. The interviews were based on the framework developed in Section 2. For ease of readership, similar to above, the discussion will be categorised into the three project elements: (a) technical considerations; (b) project enabling structure and; (c) support structure. This section will focus on the key criteria identified from the analysis of the interviews. Additionally, areas with the greatest need for improvements are highlighted. Applicable quotes taken from the interviews are used to illustrate the discussion. For reasons of confidentiality interviewees are hereafter referred to as 'manufacturer', 'advisor' and 'project developer' and the applicable number shown in Table 2. For example, comments from an Energy Advisor in Peru (position 2 in Table) will be referred to as (Advisor 2).

In order of importance, key sustainability criteria are shown in Fig. 4. While this research assessed the importance and the extent to which these are practised of 40 criteria, only the first 10 sustainability criteria are discussed in the sections below.

3.1. Key sustainability criteria within the technical element of pico-PV

Within the technical element of pico-PV, design decisions can have a large influence on the end-user and on the product success [60]. Henceforth this part will draw on the design and end-user stages along the value-chain. Focusing on: (1) the easy and safe product operation; (b) the quality of materials used, the material standards, and the component durability.

3.1.1. Easy and safe operation

The easy and safe operation has been identified as a key sustainability criterion. Aspects highlighted by experts are in line with the findings from the literature review. While the easy product operation was not a concern of the experts, they highlight that the product safety (especially the battery) is a key concern.

"*People are scared of new products especially when they* [*the products*] *are electronics*" (Manufacturer 20). This is clearly manifested in product design today as more sophisticated products enter the market. This is particularly evident in Africa where the Lighting Africa certification was initially introduced. This greatly contributed to the improved technical performance of products through quality checks on the production line

Table 2
Roles and country of expertise of 35 interviewees.

No	Type	Current position	Country of expertise
1	Manufacturer	Co-founder and CEO	India
2	Advisor	Energy Advisor	Peru
3	Advisor	Energy Consultant	Senegal
4	Developer	Director of Operations	Uganda
5	Advisor	Head of Programme	Liberia
6	Developer	Executive	India
7	Advisor	Chairman	Kenya
8	Developer	Managing Director	Indonesia
9	Manufacturer	Programme Director South-America	Peru
10	Advisor	Energy Advisor	Bangladesh
11	Advisor	Consultant	Senegal
12	Manufacturer	Director	Cambodia
13	Manufacturer	Global Marketing and Program Management	Uganda
14	Advisor	Senior Advisor Renewable Energy	Kenya
15	Advisor	Head of Programme coordinator South-America	Bolivia
16	Manufacturer	Founder	South Africa
17	Advisor	Energy Advisor	Uganda
18	Advisor	Programme Head East Africa	Kenya
19	Developer	Project Manager	Cambodia
20	Manufacturer	Country Manager	Uganda
21	Manufacturer	Brand-Building Manager East Africa	Uganda
22	Advisor	Director	Nepal
23	Manufacturer	Head of Global Partnership	India
24	Developer	Director	India
25	Manufacturer	Managing Director Latin America	Bolivia
26	Advisor	Energy Advisor	Peru
27	Manufacturer	Manager Engineering Department	Ethiopia
28	Advisor	Energy Advisor	Bangladesh
29	Advisor	Energy Advisor	Senegal
30	Advisor	Head of Programme coordinator Africa	Senegal
31	Advisor	Director and Partner	Uganda
32	Advisor	Director	Global
33	Developer	Director	Peru
34	Developer	Manager	Uganda
35	Manufacturer	Founder & Director	Global

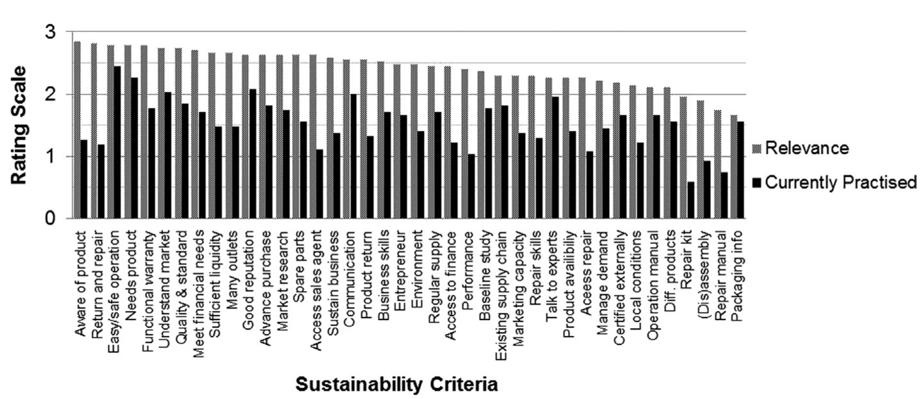

Fig. 4. Key sustainability criteria [sustainability criteria ranked by product value chain (descending)].

(Manufacturer 16). However, while the ease of operation does not require much attention, the safety of the product has raised more concern, particularly with regard to the battery. A developer of quality tests writes that, "*the battery is the critical aspect, sometimes the batteries are poisonous and lithium batteries can even explode*" (Advisor 22). The battery quality has also been highlighted as the main hazard for the environment. However, because product development is driven by the ability to generate business (Advisor 26), the environment rarely is an argument, as it does not influence consumer choice. Additionally, batteries are the main cause of early product failure. This is because technical performance studies are not carried out in the field and laboratory tests fail to resemble real life conditions such as extreme climates (Advisor 02). Whilst, at present, the technical performance studies receive little attention, experts emphasise the need for performance tests of at least one year[14] duration before product rollout. However, such tests are extremely expensive (Manufacturer 16; Developer 24) and hence, according to an Energy Advisor (22), "*this goes against the private sector as it is not economically viable; a company will not be able to afford this.*" Additionally, the market is very dynamic with many new actors entering the market. Fast product rollout is key to the success of their business to avoid that the product is not out-dated (Advisor 22). Hence, testing is often performed *during* product rollout (Manufacturer 09).

[14] This is in accordance with the Lighting Africa (LA) regulations [76].

3.1.2. Quality of materials, material standards, and component durability

This criterion is concerned with the quality of the product with regard to the materials and components used. Additionally, it draws attention to the possibility of designing products with standard components – to facilitate component replacement and ease of repair.

At present, the market is flooded with low quality products that greatly harm the uptake of solar products, particularly batteries (Advisor 03 & 29; Developer 03; Manufacturer 16). "*People buy products because they are cheap; then they break and people say that solar does not work*" (Advisor 14). While people don't choose products based on the quality of materials used, products are picked based on their performance and previous consumer experience (Advisor 18). Despite this, many product developers fail to deliver quality products as cheapness is overemphasised. A Project Developer (24) in India explains that, "*most producers in the world make cheap products and they even lack lumen output. People need modern light where people can see…*"

3.1.3. Meeting the financial capacities and breaking even

To ensure uptake of pico-PV and avoid subsidies, the products have to meet the financial capacities whilst covering all costs and making provision for profits along the value chain, profit is essential to sustain a business (Manufacturer 13). Although, manufacturers are placing great emphasis on meeting the financial capacities and developing new business models, it is challenging. A major product manufacturer and distributor states, "*finally after four years of operation we have broken-even*" (Manufacturer 13). However, delivering an affordable product is key to the sustainability of the market and should be the main priority (Advisor 28). Unfortunately, as manufacturers fail to understand the difference between affordable and cheap, many product designers fail to make provision for the low financial capacities of the target consumers and deliver cheap, low quality products (Developer 24). A Manufacturer (16) of high-end pico-PV products states that, "*everyone always tries to design and manufacture as cheap as possible but it is difficult to produce a quality product and have it cheap.*" One reason for this misconception is that because of the high costs associated with it, many actors fail to undertake good quality market research. Instead, it is often conducted through an analysis of existing data or expert consultation. As a consequence, many pico-PV products are based on incorrect assumptions, and hence their initial design and lumens is often based on the traditional kerosene lamp and fail to meet actual customer aspirations. Advisor 18 states that, "*many people think it is essential that it looks like kerosene lamps but it is not essential to look backwards.*" Although, there is clear difference in design and performance preference between different geographical locations, many product developers fail to investigate this, (Advisor 15) and instead opt for product adjustment over time (Manufacturer 25 and 16).

3.2. Key sustainability criteria within the product enabling structure of pico-PV

At present the market is experiencing a technology push, mainly by the manufacturer. However, to ensure sustainable product deployment, market demand must exist or be created (Advisor 15 and 02). This is in line with the findings from the literature review where the lack of infrastructure and retailer skills were identified as key barriers to PV technologies [5–8]. This discussion is based on: (a) product awareness; (b) the need for the product; (c) the retailer understands the market; (d) the sufficient liquidity of importer, distributor and retailer and; (e) the retailer has many outlets. Points (a) and (b) are discussed below in the same point 'the end-user is aware of product benefits and has a product need'.

3.2.1. The end-user is aware of product benefits and has a product need

The end-user's awareness of product existence and benefits is considered one of the key points to sustainable product deployment. Despite its importance, it has the biggest gap between its importance and the extent to which it is currently practised. This can be linked to the lack of marketing capacity of the retailer. However, one of the main challenges of creating product awareness through marketing is the high capital cost associated with it. Hence, awareness creation is mostly driven by word-of-mouth, a slow process (Advisor 18). The major drawback is that benefits are not well communicated and products are simply purchased based on price. Hence, it is important that high quality pico-PV products are distributed (Developer 04). Nevertheless, if there is no motivation for purchasing the product, uptake will remain low. For example, 23 experts (65%) ranked the 'need for an alternative lighting method' as the most important criterion. However, to date many potential end-users do not know that they need the product (Developer 24). This is because there are still low levels of pico-PV exposure. While experts see a clear need for pico-PV products as fuel prices are high, especially in areas where there is limited access to fuel, rural customers may not. High fuel prices and the low rural electrification rates create great business opportunities, especially in East-Africa (Developer 04; Advisor 18).

3.2.2. Retailer understands the target market

Understanding the target market has been identified as one key criterion. While it is believed that the local retailer knows the area and therefore meets the needs of the target market (Developer 04), concerns remain. For example, the retailer regularly fails to consider the quality of the products, an oversight that is particularly common in rural areas and purchases low-quality products. A reason seems to be the limited financial capacities of the retailer. Subsequently the end-user is forced to purchase cheap low-quality products (Advisor 02).

3.2.3. The importer and distributor has sufficient liquidity

The financial capacity of the importer and distributor is a key criterion to the sustainable deployment as it ensures product availability. Additionally, as discussed above, it enables the retailer to purchase a product adequate for the target area. This is currently critical as product demand is increasing (Advisor 18). However, many start-ups (NGOs or social entrepreneurs) are restricted by their financial capacity and hence face liquidity problems (Advisor 18); this is particularly evident in Asia. Consequently, the importer is forced to wait for importing new products until the retailer can purchase new stock, which only occurs once stocks are exhausted (Advisor 18 and 29; Developer 04). Further to this, pico-PV products have a high initial/capital cost, thus if supplier/importer do not offer purchase on credit to the retailer, which is rarely the case, this stunts product supply to rural areas. Retailers simply do not have the cash flow to purchase new products until the original purchase has been sold (Advisor 18; Manufacturer 20; Developer 24). According to an Energy Advisor (18) responsible for East Africa, "*the retailer stocks as little as he can because products are expensive and he requires upfront cash.*" The need for advance purchase is the biggest hindrance for local entrepreneurs wanting to enter the pico-PV market because they lack access to finance (Developer 04; Advisor 18). The lack of stock is of great concern because the supply chain regularly fails as major delays occur and products are simply unavailable (Advisor 28 and 02). At present supplies into a region

tend to be limited to an average of three to four quality suppliers (Advisor 02). As, "*everyone is going for the low hanging fruit – where it is easiest to get the products to*" (Advisor 18). Hence, the majority of products are sold in urban or semi-urban areas (Developer 04). Clear methods of retail need to be established as uptake greatly depends on the ability of the end-user to easily purchase the products (Manufacturer 09). A major drawback of this is that products become too expensive for target consumers. However, while it is important to provide an affordable product, it is not necessary to offer cheap products (Developer 24). Often the customers' operational expenditures are greater than the capital cost of kerosene lanterns; e.g. in Kenya the cost of purchasing kerosene over 6 months is far greater than the cost of a kerosene lantern (Advisor 18).

3.2.4. Retailer has many outlets or can reach customers

Entrepreneurs develop innovative methods to bring the products to rural customers. However, rural product deployment is currently not significant (Developer 24; Advisor 02) due to a lack of local representatives. At present, instead of selling through retail outlets, which aids product sales/distribution (Advisor 18), pico-PV products are mainly sold through rural sales agents (*ibid*). This is because most retailers believe, whilst not carried out, that it is necessary to establish new retail outlets when a new product/range is being sold. Sales agents are a cheaper alternative but have two main drawbacks: (a) it is difficult for sales agents to reach rural areas due to the lack infrastructure and efficient transport methods (Developer 04) and (b) the customer then has difficulties in reaching the sales agent (Advisor 26). Additionally, there is currently limited demand for the product, and hence the retailer is unable to sustain business solely through sales of solar products (Developer 04 and 24). According to Manufacturer (09), "*if the company is only selling solar products, the market needs to be larger for them to sustain business.*"

3.3. Key sustainability criteria within the support structure of pico-PV

The need for a support structure is a relatively new concept, which was pushed through the establishment of the Lighting Africa campaign. Subsequently it has received comparatively little attention. The two criteria covered in the support structure are: (a) a system for return and repair of products is established; and (b) a functional warranty exists.

3.3.1. A system for return and repair of products is established

As highlighted in the previous section, a functional warranty relies on a good distribution network. However, at present a system of replacing and returning faulty products does not exist on a commercial scale as it is simply not financially feasible (Advisor 31); particularly in remote areas (Developer 24). According to Energy Advisor (14) from Kenya, "*after-sale service is still a problem; no one has after-sale services in villages. 300 km away from Nairobi, cost of logistics is too much.*" The key is to return products back up the entire supply chain by defining clear roles for all stakeholders along the value chain. However, it remains unclear who is responsible; who manages and who pays for product return (Advisor 29). According to an Energy Advisor (18), "[*the*] *responsibility lies with the importer or manufacturer.*" Furthermore, clarification is required regarding what happens to the broken products when they are returned to the manufacturer (Advisor 22). In line with this, to date, faulty products are often exchanged with the delivery of new stock (Developer 04). However, at present there are difficulties in supplying products to and within developing countries. To surmount this, project developers have started to use existing supply networks for product delivery (Advisor 18). Nevertheless, for more efficient product return a standardised return system must be put in place as project developers will not be able to carry on with current methods in the longer term. To overcome the high cost of product return, project developers (particularly in Asia) have attempted in-country assembly and disassembly (Advisor 15). A Project Developer (04) with experience in Bangladesh and Uganda explains that: "*especially in Uganda, people have a prejudice because the product has been imported from developed countries. In Bangladesh, however, people have self-belief if the products have been developed locally in their own country. This increases confidence of the people in the after-sales servicing and repair of the products.*" However, at present this is simply not feasible in the majority of developing countries as the market is too small and, in Africa for example, a fully assembled product comes with import tax exemption (Advisor 18 and 15) therefore not helping the domestic market.

3.3.2. A functional warranty exists

The analysis shows that a functional warranty is a must. However, a Project Developer (24) explains that, "in practice [a warranty does] not really [exist], but a warranty is often being offered. Customers are based far away making repair and replacement difficult." Considering the currently underdeveloped infrastructure and the costs associated with a warranty, it is questionable whether the development of higher quality products is more appropriate for this kind of market; more expensive, better quality products do not require such an infrastructure (Advisor 15). For example, a major selection criterion for project developers should be product certification as this provides a certain quality standard and in theory lowers the risk for the end-user (Manufacturer 09; Advisor 29). Additionally, without a warranty of at least one year, products will not be certified by for example Lighting Africa (Advisor 18). Despite the small uptake of warranties, experts feel that one year is insufficient because, with current technical standards, it is not onerous.

4. Recommendations

Based on the analysis of the forty sustainability criteria covered in this research (shown in Fig. 4), in this part of the paper, five methods that can help the sustainable development and deployment of pico-PV products are discussed.

4.1. Raise awareness for certification and creating market reassurance

The product itself is key to the sustainability of pico-PV as a good product minimises early product failure. This in turn can help to re/establish trust into the pico-PV sector and minimise environmental harm. Although there have been some significant improvements in product design during recent years, a large number of products still have a short lifespan and toxic batteries. In spite of this, the product design stage performs (on average) better than the other stages along the product value chain. One potential method for improving quality (in particular battery properties) is to raise awareness amongst project developers of the need to only sell or distribute certified products as this ensures a certain product quality. In an aim to encourage brand owners to get product certification and thus improving the quality of available products, product developers need reassurance from the market, i.e. the market is stable and worthy of the high investment into product certification. Product certification is potentially too expensive for producers as it is often simply not financially feasible, since product uptake remains low. Additionally brand

owners have to balance the market's needs, wants and financial capabilities against their own desire to maximise profits (crunch point). This is particularly important in Asia where poor quality products dominate the market.

4.2. Introduce support mechanisms to facilitate local repair

Another method to make product deployment more sustainable is for the brand owner to provide support that facilitates local repair (such as delivering a tool kit and spare parts with every batch, providing a graphical repair manual and allow for local (dis)assembly). Local repair is particularly important as, at present, the different stakeholders fail to meet the requirements to return products for repair. However, whilst it is important to provide these support instruments, they are only as good as their ability to meet the local needs and conditions. For example, many people lack sufficient skills and the availability of spare parts is hampered through difficulties in supply. Solutions include: making manuals with clear visual graphics, and enabling the purchase of spare parts from different sources.

4.3. Use existing supply channels and establish in-country (dis) assembly

In an aim to make delivery into remote areas financially feasible, suppliers have to find reliable methods to deliver products into and within the country. This is a fundamental condition for establishing a functional product return and repair system at the point of product supply. There are a number of means for improving the current distribution methods, which include: (a) the use of an existing supply network and (b) the establishment of in-country assembly and disassembly. However, whilst the first is already practised to a certain extent, the latter requires large upfront capital investment. Nevertheless it is a potential method to overcome the liquidity problems faced, particularly by the product importers. Whilst this is important for the supply side, brand owners bear the responsibility of establishing in-country factories. The divergence in opinion here is significant; some experts believe this is of great importance, whilst others see it to be insignificant. The onus on the brand owner to create in-country factories is beneficial in that it can help to overcome the irregular supply hampered by the supplier's liquidity in addition to in-country repair and availability of spare parts. Additionally, to limit the need for product return and repair, product designers should simply produce more resilient products.

4.4. Introduce financial support mechanism at product supply stage

Providing suppliers with access to credit can help to overcome the constraints associated with the limited liquidity of many suppliers. The current system compromises supply reliability, which in turn generates zero customer/retailer satisfaction and zero loyalty. To combat this, a more cooperative relationship can be initiated by suppliers offering products on credit to retailers. This is currently rarely done because of the high risk associated with providing products on credit to local project developers since a standardised system for providing credit ratings does not exist in most developing countries. This allows for a more stable point of sales to help establish product uptake, which greatly depends on the ability of the end-user to easily purchase the products. More importantly, continuous supply can help retailers to sustain their business. Additionally, by offering credits (financial or product on credit) at the point of supply, the creditor can introduce conditions for the supplier in an aim to make product supply more sustainable (e.g. purchase of certified products, product return and facilitation of repair). This can potentially be done by offering products on credit to a regional distributor who then in turn micro-manages distribution.

4.5. Undertake marketing campaign

At present, product suppliers face difficulties in delivering products to rural areas as the market currently has to create the demand for this technology (technology push). In an aim to move towards a technology 'pull' of rural customers, it is essential to create awareness of the product and its benefits. This research finds that the lack of product awareness amongst the end-users is the 'least practised' with high relevancy of sustainability indicating a major market failure. At present there are two main reasons/factors that hinder successful marketing: (a) the lack of capacity of the retailer to undertake marketing and (b) the lack of clarity on ownership of the marketing responsibility. There is a clear need to communicate the importance of marketing and clarify the ownership mechanism; currently project developers accuse brand owners of being wholly accountable for marketing and vice-versa, evident from the expert interviews. Additionally, retailers, in an aim to sustain their business, often have other priorities aside from marketing and, in addition to sufficient financial capacity, require the competence to demonstrate the technology to the end-user. One potential solution is to undertake global marketing campaigns. Large marketing campaigns are the job of the brand owner but, due to the associated high capital costs, they cannot be achieved successfully without the support of the government and donor funds (not product specific)0.[15] This in turn raises mass awareness and allows for smaller scale awareness and demonstration campaigns by the brand owners. For a more in depth review on method for BoP marketing refer to 'marketing innovative devices for the base of the pyramid' by HYSTRA [61].

5. Conclusion

This research has investigated the most important criteria pertaining to the sustainable development and deployment of pico-PV. Subsequently, methods for enhancing the sustainable implementation of pico-PV technologies have been identified. The research has revealed that the most important criteria for the sustainable deployment of pico-PV systems at each stage along the value chain are: (a) product design stage: the easy and safe operation of the product; (b) supply chain stage: establishment of a system for product return (facilitating repair); (c) retail stage: the retailer understands the target market; and (d) end-use stage: the end-user is aware of the product's existence and of its benefits. From the present research it is apparent that criteria (b) establishment of a system for product return and (c) the retailer understands the target market are the areas of greatest concern, primarily because they are the least practised in the countries studied. Additionally, five methods that can contribute to the sustainable implementation of pico-PV technologies have been identified as

1. Raising awareness for certification and creating market reassurance;
2. Introducing support mechanisms to facilitate local repair;
3. Using existing supply channels and establishing in-country (dis)assembly;

[15] The help of the government/donor organisations is particularly important for smaller organisations. These are incapable of mobilising large resources to have global campaigns and consequently the products of large organisations/enterprises monopolise.

4. Introducing financial support mechanisms at product supply stages;
5. Undertaking marketing campaigns.

In the past, most emphasis has been placed on product design. Despite the importance of design, the present research shows that more importance must be given to meeting the needs of the different stakeholders along the pico-PV value chain to ensure sustainable product deployment. This is particularly important at present because importers and project developers are failing to meet the local needs for sustainable product deployment on the ground.

Acknowledgement

We are grateful to the comments of the reviewers that greatly improved this article. Additionally, the authors wish to express sincerest thanks to the following people and organisations for their continuous support throughout this research: GIZ (HERA) for facilitating and funding this research; in particular: Dr. Marlis Kees, Heike Volkmer, Bozhil Kondev, Monika Rammelt and Gunnar Wegner; the 35 interviewees for their time in taking part in this research and for sharing their experience; Sidney Sussex College for additional research funding; Colin Oram, Diana Nenz, Edward Pitt and Paul Hatfield.

References

[1] Lighting Africa (International Finance Corporation). Solar lighting for the base of the pyramid-overview of an emerging market. Technical report. Washington, DC; 2010.
[2] Lighting Africa (International Finance Corporation). The off-grid lighting market in Sub-Saharan Africa: market research synthesis report. Technical report. Washington, DC; 2011.
[3] Díaz P, Arias C. Solar home system electrification in dispersed rural areas: a 10-year experience in Jujuy, Argentina. Prog Photovoltaics: Res Appl 2011:297–307.
[4] Lahimer AA, Alghoul MA, Yousif F, Razykov TM, Amin N, Sopian K. Research and development aspects on decentralized electrification options for rural household. Renewable Sustainable Energy Rev 2013;24:314–24.
[5] Lahimer AA, Alghoul MA, Sopian K, Amin N, Asim N, Fadhel MI. Research and development aspects of pico-hydro power. Renewable Sustainable Energy Rev 2012;16:5861–78.
[6] Chaurey A, Kandpal TC. Assessment and evaluation of PV based decentralized rural electrification: an overview. Renewable Sustainable Energy Rev 2010;14:2266–78.
[7] Debelak M. The bumpy road to the BoP-addressing the challenges of distribution to the base of the pyramid – a Ghanaian study. LAP LAMBERT Academic Publishing, Gothenburg, Sweden; 2011.
[8] Yadoo A. (International Institute for Environment and Development). Delivery models for decentralised rural electrification case studies in Nepal, Peru and Kenya. Technical report. London, UK; 2012.
[9] Polak P. Out of poverty: what works when traditional approaches fail. San Fransisco: Berrett-Koehler Publishers Inc.; 2008; 200.
[10] Hammond A, Kramer W, Katz R, Tran J. (IFC/World Resource Inst.). The next 4 billion: market size and business strategy at the base of the pyramid. Technical report. Washington, DC; 2007.
[11] Court D, Narasimhan L. (McKinsey Management Consultancy). Capturing the world's emerging middle class. McKinsey Quarterly, Delhi; July 2010.
[12] Grüner R, Lux S, Reiche K, Wolf R. Quality assessment of solar lanterns. Rural electrification and commercial use. In: Proceedings of the 1st small PV-applications conference. Ulm, Germany: Ostbayrisches Technologie-Transfer-Institute e.V.; 2009.
[13] Crawley K, Holland R, Gitonga S. (Practical Action). Improved designs for solar rechargeable lanterns and their development and marketing in developing countries. Technical report. Rugby, UK; 2001.
[14] ESMAP (The International Bank for Reconstruction and Development/The World Bank). Technical and economic assessment of off-grid, mini-grid and grid electrification technologies. Washington, DC; 2007.
[15] Narula K, Nagai Y, Pachauri S. The role of Decentralized Distributed Generation in achieving universal rural electrification in South Asia by 2030. Energy Policy 2012;47:345–57.
[16] Yannick Glemarec. Financing off-grid sustainable energy access for the poor. Energy Policy 2012;47:87–93.
[17] Aron J, Kayser O, Liautaud L, Nowlan A. (HYSTRA). Access to energy for the base of the pyramid. Technical report; 2009.
[18] Gradl C, Knoblauch C. (ENDEVA). Energize the BoP! Energy business model generator for low-income markets. Technical report. Berlin, Germany; 2012.
[19] Sloan D, Kleinfeld R. Let there be light: electrifying the developing world with markets and distributed energy. 1st ed. Washington, DC: Truman National Security Institute; 2011.
[20] IFC (International Finance Corperation). From gap to opportunity: business models for scaling up energy access. Technical report. Washington, DC; 2012.
[21] WBCSD [Internet]. Geneva: WBCSD – World business council for sustainable development 2012 [updated 2012; cited 2012 Aug 02]. Available from: 〈http://wbcsd.org/home.aspx〉.
[22] Karamchandani A, Michael Kubzansky, Frandano P. (Monitor Group) Emerging markets, emerging models: market-based solutions to the challenges of global poverty. Technical report; 2009.
[23] Chaurey a, Kandpal TC. Solar lanterns for domestic lighting in India: viability of central charging station model. Energy Policy 2009;37:4910–8.
[24] Zerriffi H. Innovative business models for the scale-up of energy access efforts for the poorest. Curr Opinion Environ Sustainability 2011;3:272–8.
[25] Mohanty P, Dasgupta N, Sharma A. Centralized solar lantern charging station under “lighting a billion lives” campaign: a technological evolution. Prog Photovoltaics: Res Appl 2010;18:516–34.
[26] Frischmann B. Infrastructure: the social value of shared resources. New York, Oxford: Oxford University Press; 2012.
[27] Palit D. Solar energy programs for rural electrification: experiences and lessons from South Asia. Energy Sustainable Dev 2013;17:270–9.
[28] Müggenburg H, Tillmans A, Schweizer-ries P, Raabe T, Adelmann P. Energy for Sustainable Development Social acceptance of PicoPV systems as a means of rural electrification – q socio-technical case study in Ethiopia. Energy Sustainable Dev 2012;16:90–7.
[29] IEA/OECD (International Energy Agency/The Organisation for Economic Co-operation and Development (OECD)). Energy for all: financing access for the poor. Technical report. Paris; 2011.
[30] Baziliana M, Welscha M, Divanb D, Elzingac D, Strbacd G, Howellse M. et al. Smart and just grids: opportunities for subSaharan Africa Morgan. Report. Imperial College London, Energy Future Lab. London; 2011.
[31] IEA/OECD (International Energy Agency/The Organisation for Economic Co-operation and Development (OECD)). Key World Energy Statistic. Technical report. Paris; 2011.
[32] IEA (International Energy Agency) [Internet]. Paris: IEA; [updated 2012; cited 2012 Apr 15]. IEA Access to Electricity. World Energy Outlook 2011. Available from: 〈http://iea.org/weo/electricity.asp〉.
[33] Practical Action. Poor people' s energy outlook 2012. Technical report. Rugby, UK; 2012.
[34] UNDP. Integrating energy access and employment creation to accelerate progress on the MDGs in Sub-Saharan Africa. Technical report. New York, USA; 2012.
[35] Pereira MG, Sena JA, Freitas MAV, Da Silva NF. Evaluation of the impact of access to electricity: a comparative analysis of South Africa, China, India and Brazil. Renewable Sustainable Energy Rev 2011;15:1427–41.
[36] Hogarth JR. Promoting diffusion of solar lanterns through microfinance and carbon finance: a case study of FINCA-Uganda's solar loan programme. Energy Sustainable Dev 2012;16:430–8.
[37] Silva IPD, A Sendegeya, G Bajjabulindi. Small scale carbon sequestration using solar powered LED lanterns: a case study in uganda. Rural Electrification and Commercial Use. In: Proceedings of the 1st small PV-applications conference. Ulm, Germany: Ostbayrisches Technologie-Transfer-Institute e.V.; 2009.
[38] Weitzel R, Weitzel R. Off-grid lighting solutions for least developed countries. In: Proceedings of the 1st small PV-applications conference. Ulm, Germany: Ostbayrisches Technologie-Transfer-Institute e.V.; 2009.
[39] Modi V, McDade S, Lallement D, Saghir J. (The International Bank for Reconstruction and Development/The World Bank and the United Nations Development Programme). Energy services for the millennium development goals. Technical report. New York; 2005.
[40] Chaurey A, Krithika PR, Palit D, Rakesh S, Sovacool BK. New partnerships and business models for facilitating energy access. Energy Policy 2012;47:48–55.
[41] Asperen MJ. Solar lighting for the off-grid BOP in Kenya: an analysis of business models and challenges to growth [dissertation]. VU University Amsterdam; 2010.
[42] Mayer-Tasch L. (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH). GTZ solar lamps (pico-PV) field test: consumer preferences and impacts ongoing GTZ solar lamps study. Kampala; 2010.
[43] IFC (International Finance Corperation, The World Bank Group). Lighting Asia: solar off-grid lighting. New Dehli, India; 2012.
[44] EnDev. (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH). What difference can a PicoPV system make? Eschborn, Hesse; 2010.
[45] Glavič P, Lukman R. Review of sustainability terms and their definitions. J Clean Prod 2007;15:1875–85.
[46] Brundtland G. Towards sustainable development. Our common future: the world commission on environment and development. Oxford, United Kingdom: Oxford University Press; 1987, p. 44–66.
[47] Faber N, Jorna R, Engelen JVan. The Sustainability of “ Sustainability” – a study into the conceptual foundations of the notion of “Sustainability”. J Environ 2005;7:1–33.
[48] Spangenberg JH, Pfahl S, Deller K. Towards indicators for institutional sustainability: lessons from an analysis of Agenda 21. Ecol Indicators 2002 61–77.

[49] Ramírez A, Hoogwijk M, Hendriks C, Faaij A. Using a participatory approach to develop a sustainability framework for carbon capture and storage systems in The Netherlands. Int J Greenhouse Gas Control 2008;2:136–54.
[50] Yadoo A, Cruickshank H. The role for low carbon electrification technologies in poverty reduction and climate change strategies: a focus on renewable energy mini-grids with case studies in Nepal, Peru and Kenya. Energy Policy 2012;42: 591–602.
[51] Ilskog E. Indicators for assessment of rural electrification – an approach for the comparison of apples and pears. Energy Policy 2008;36:2665–73.
[52] HERA. (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH). Sustainability assessment of improved cookstove dissemination. Technical report. Eschborn, Hesse; 2011.
[53] Tillnabs A, Schweizer-Reis P. Mental Model in technical development cooperation – exemplary analysis of rural electrification with solar home systems. In: TUC, editor. Proceedings of the 1st small PV-applications conference. Ulm, Germany: Ostbayrisches Technologie-Transfer-Institute e.V.; 2009.
[54] Paul A. Solar pico systems – problems, opportunities and solutions. Proceedings of the 2nd small PV-applications conference. Ulm, Germany: Ostbayrisches Technologie-Transfer-Institute e.V.; 2011.
[55] Junior V. Rural electrification with SHS at riverside villages in the Amazon region: social factors contributing to the success of technical projects and plans. In: Proceedings of the 2nd small PV-applications conference. Ulm, Germany: Ostbayrisches Technologie-Transfer-Institute e.V.; 2011.
[56] Barnes DF, Openshaw K, Smith KR, van der Plas R. What makes people cook with improved biomass stoves. World Bank, Washington DC; 1994.
[57] Kees M, Feldmann L. The role of donor organisations in promoting energy efficient cook stoves. Energy Policy 2011;39:7595–9.
[58] Schutze E. (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH). Lesson learned from ProBEC's impact assessment surveys, knowledge management system, and public relations strategy. Technical report. Eschborn, Hesse; 2010.
[59] Hellpap C, Raabe T, Pfisterer AN. Ways to protect consumers from low quality picoPV products. In: Proceedings of the 2nd small PV-applications conference. Ulm, Germany: Ostbayrisches Technologie-Transfer-Institute e.V.; 2011.
[60] Boztepe S. Toward a framework of product development for global markets: a user-value-based approach. Des Stud 2007;28:513–33.
[61] HYSTRA (Hybrid Strategies Consulting). Marketing innovative devices for the base of the pyramid. Technical report. Paris; 2013.
[62] Prahalad CK, Hart SL. The fortune at the bottom of the pyramid. Strategy+Bus 2002;1:1–16.
[63] Schlag N, Zuzarte F. (Stockholm Environment Institute). Market barriers to clean cooking fuels in sub-Saharan Africa: a review of literature. Working paper. Stockholm; 2008. p. 1–28.
[64] HERA (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH). Lessons learned from improved cooking stove projects. Technical report. Eschborn, Hesee; 2011.
[65] Cordes L. (Global Alliance for Clean Cookstoves, The World Bank Group). Igniting change: a strategy for universal adoption of clean cookstoves and fuels. Technical report. Washington DC, DC; 2011.
[66] Ostrom TK. Considering sustainability factors in the development project life-cycle: a framework for increasing successful adoption of improved stoves [dissertation]. Michigan Technological University; 2010.
[67] Jan I. What makes people adopt improved cookstoves? Empirical evidence from rural northwest Pakistan Renewable Sustainable Energy Rev 2012;16: 3200–5.
[68] Kowsari R, Zerriffi H. Three dimensional energy profile: a conceptual framework for assessing household energy use. Energy Policy 2011;39:7505–17.
[69] Djédjé M. (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH). Sustainability of stove dissemination in Bushenyi and Mbale Districts Uganda. Technical report. Kampala, Uganda; 2010.
[70] HEDON. Interview with Ron Bills, Chairman and CEO of Envirofit. Boiling Point 2010(58):48.
[71] Bailis R, Cowan A, Berrueta V, Masera O. Arresting the killer in the kitchen: the promises and pitfalls of commercializing improved cookstoves. World Dev 2009;37:1694–705.
[72] El Tayeb Muneer S, Mukhtar Mohamed EW. Adoption of biomass improved cookstoves in a patriarchal society: an example from Sudan. Sci Total Environ 2003;307:259–66.
[73] Bishop S, Blum J, Pursnani P, Bhavnani A. Marketing lessons from the Room to Breathe Campaign. Boiling Point 2010;58:48.
[74] Shrimali G, Slaski X, Thurber MC, Zerriffi H. Improved stoves in India: a study of sustainable business models. Energy Policy 2011;39:7543–56.
[75] Reikat A. (Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH). Marketing – lessons learnt in Burkina Faso and Mali. Technical report. Eschborn, Hesse; 2007.
[76] IFC (International Finance Corporation, The World Bank Group), Lighting Africa. Solar lighting for the base of the pyramid – overview of an emerging market. Technical report. Washington DC (DC); 2010.